ARR Jan. 1943

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED
January 1943 as
Advance Restricted Report

~~ADDITIONAL DESIGN~~ CHARTS RELATING TO THE STALLING OF TAPERED WINGS

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NACA

WASHINGTON

L - 271

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ADVANCE RESTRICTED REPORT

L-271

ADDITIONAL DESIGN CHARTS RELATING TO THE STALLING OF TAPERED WINGS

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SUMMARY

Charts are presented to show the effects of taper ratio, thickness ratio, aspect ratio, and Reynolds number on the spanwise location of the initial wing stall and on the maximum lift coefficient of the wing. These stall charts supplement the charts given in NACA Report No. 703 by including additional taper ratios and a root thickness ratio of 0.24 tapering to 0.09 at the tip. For a root thickness ratio of 0.24, the effect of increasing the aspect ratio to 18 is investigated.

INTRODUCTION

At the request of the Bureau of Aeronautics, Navy Department, the stall charts presented in reference 1 for the NACA 230 airfoil series have been extended to include taper ratios of 3 and 4 and a root thickness ratio of 0.24 tapering to 0.09 at the tip. The present report, therefore, may be considered a supplement to reference 1. The combined scope of the stall charts of reference 1, designated A, and of the present work, designated B, is summarized in the following table:

TABLE I

[Aspect ratio, 6]

Thickness ratio		Reference designation				
		Taper ratio				
Root	Tip	1	2	3	4	5
0.12	0.09	A	A	B	B	A
.15	.09	A	A	B	B	A
.18	.09	A	A	B	B	A
.21	.09	A	A	B	B	A
.24	.09	B	B	B	B	B

For the wing with the root thickness ratio of 0.24, the effect of increasing the aspect ratio to 18 was also investigated.

METHOD AND RESULTS

The assumptions and the method used in the present calculations are identical with those given in reference 1. Figure 1 shows the assumed typical thickness-ratio variation along the span for the wing having an NACA 23024 section at the root and tapering to an NACA 23009 section at the tip. The figure includes taper ratios of 1 through 5. These variations, as noted in reference 1, are independent of aspect ratio. For all cases, the variation of the actual thickness along the span was linear.

The results are presented in figures 2, 3, and 4 and are summarized in table II.

Figure 2 presents the spanwise distribution, based on lifting-line theory, of the section lift coefficient c_l. Figure 2(a) gives the section lift coefficients $c_{l_{a1}}$ for wings without aerodynamic twist at an over-all wing lift coefficient of 1 for taper ratios of 3 and 4 and aspect ratios of 6, 12, and 18. Figure 2(b) gives section lift coefficients $c_{l_{b_{10}}}$ for wings with 10° washout at $C_L = 0$.

Figures 3 and 4 show the distributions of c_l at the wing stall compared with section values of $c_{l_{max}}$. The figures are for Reynolds numbers of 4,000,000, 8,000,000, and 14,000,000 based on the mean wing chord. The values of $c_{l_{max}}$ are based on two-dimensional test data obtained from reference 2 and corrected to the local Reynolds number at each section. The Reynolds number corrections were determined from data given in reference 3, which were extrapolated for section Reynolds numbers greater than 8,000,000. The $c_{l_{max}}$ values for thickness ratios higher than 0.21 were determined by extrapolating the data from reference 2. A partial check of this extrapolation was obtained by a comparison of some of the values derived with experimental data presented in reference 4. Figure 3 presents the results for an aspect ratio of 6 and taper ratios of 3 and 4.

The figure includes thickness ratios at the root of 0.12, 0.15, 0.18, 0.21, and 0.24, each tapering to 0.09 at the tip. Figure 4 presents the results for the NACA 23024-09 airfoil for aspect ratios of 6, 12, and 18, and taper ratios of 1 through 5.

Table II summarizes the results of the present study for the 23024-09 wing for five taper ratios, three aspects ratios, and three Reynolds numbers. This table shows the position along the wing b_s as a fraction of the semispan at which stalling is first indicated to occur and the wing maximum lift coefficients $C_{L_{max}}$.

DISCUSSION

The general trends shown by the results of the present computations are similar to those discussed in reference 1. Figure 3 and a comparison of figure 4 of this report with figure 4 of reference 1 show the effects of increasing the root thickness ratio to 0.24. The initial stall location moves inboard and the c_l and $c_{l_{max}}$ curves diverge more rapidly outboard of the stall point. This divergence outboard of the stall point with increasing thickness ratio is more pronounced for low taper ratios. There is, in addition, a reduction in the over-all wing maximum lift coefficient and in the margin between the c_l and $c_{l_{max}}$ curves inboard of the initial stall location. The increase in wing thickness ratio from NACA 23021-09 to 23024-09 reduces the calculated value for the wing maximum lift coefficient by approximately 7 percent for the lower taper ratios (r, 1 and 2) and approximately 3.5 percent for the higher taper ratios (r, 3 and 4).

Figure 4 also shows the effects of aspect ratio. It is interesting to note in the figure that the $c_{l_{max}}$ distribution curves are independent of aspect ratio for a given wing Reynolds number based on the mean wing chord. The $c_{l_{a1}}$ distribution tends to flatten out with increasing aspect ratio. (See fig. 2.) The resultant effect on the initial stall location indicated in figure 4 is that an increase in aspect ratio tends to move the initial stall location toward the center. The calculated wing maximum lift coefficient for the NACA 23024-09 airfoil varies only slightly with aspect ratio, except for extreme taper. With the extreme taper ratio of 5 and a Reynolds number of 4,000,000, increasing the aspect ratio from 6 to 12 gives a 4.5 percent increase in wing maximum lift coefficient. With a Reynolds number of 14,000,000 this increase in $C_{L_{max}}$ is reduced to less than 1 percent. Increasing the Reynolds number of the NACA 23024-09 airfoil tends to move the calculated initial stall location toward the center.

The results of the present study and the data given in reference 1 show the effect of combining increases in wing thickness ratio, aspect ratio, and taper ratio. The effect of combining these changes varies somewhat with the Reynolds number (and taper and thickness ratios). In general, for a constant taper ratio a combined increase in the thickness and aspect ratios tends to reduce $C_{L_{max}}$ and to shift the initial stall location inboard. If the taper ratio is, in addition, increased, the effect is to reduce $C_{L_{max}}$ and to widen the spanwise initial stall region. If, for example, a constant taper ratio of 2 is assumed, jointly increasing the wing thickness ratio from NACA 23012-09 to 23024-09 and the aspect ratio from 6 to 18 results in a reduction in $C_{L_{max}}$ of the order of 9 percent for Reynolds number of 4,000,000 and 16 percent for Reynolds number of 8,000,000. The initial stall region, however, moves inboard from the spanwise position of approximately 0.50 to 0.60 to the position of 0 to 0.13. If the taper ratio is, in addition, assumed to increase from 2 to 5, the combined effects of these changes in taper ratio, thickness ratio, and aspect ratio result in a reduction in $C_{L_{max}}$ slightly less than the previously mentioned one and in a widening of the spanwise initial stall region from 0.55 to 0.65 to 0.32 to 0.85 for Reynolds number of 4,000,000 and from 0.48 to 0.58 to 0.22 to 0.57 for Reynolds number of 8,000,000.

Figures 3 and 4 show, particularly for the NACA 23024-09 wing, a comparatively large spanwise gradient of the $c_{l_{max}}$ distribution. Experimental section data for the NACA 230 series indicate that the decrease in $c_{l_{max}}$ with increasing thickness ratios above 15 percent is associated with a corresponding thickening of the boundary layer. The comparatively large variation in $c_{l_{max}}$ between adjacent sections, noted for the NACA 23024-09 wing, is consequently associated, for sections at the same lift coefficient, with corresponding differences in boundary-layer thickness.

CONCLUSIONS

The results of the present study show the same general effects of variations in the taper ratio, thickness ratio, and Reynolds number on wing stalling characteristics as shown by the analysis of Report No. 703.

The specific conclusions noted mainly for the NACA 23024-09 airfoil are:

1. Increasing the aspect ratio and Reynolds number tends to move the calculated initial stall location toward the wing center; whereas increasing the taper ratio moves the initial stall position in the outboard direction.

2. The calculated wing maximum lift coefficient for the NACA 23024-09 wing varies only slightly with aspect ratio for the usual tapers and, in general, increases slightly with increasing Reynolds numbers. Increasing the wing thickness ratio from NACA 23021-09 to 23024-09 decreases the calculated value of maximum lift coefficient by approximately 7 percent for the lower taper ratios of 1 and 2 and approximately 3.5 percent for the higher taper ratios of 3 and 4.

3. In general, for a constant taper ratio, a combined increase in the thickness ratio and the aspect ratio tends to reduce the maximum lift coefficient of the wing and to shift the initial stall location inboard. If the taper ratio is, in addition, increased, the effect of the combined increases in aspect ratio, taper ratio, and thickness ratio tends both to reduce the maximum lift coefficient of the wing and to widen the spanwise initial stall region.

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TABLE II

SUMMARY OF RESULTS FOR NACA 23024-09 WING FOR INITIAL

STALL REGION AND WING MAXIMUM LIFT

Aspect ratio \ Taper ratio	1		2		3		4		5	
	b_s (fraction semispan) (a)	$C_{L_{max}}$	b_s (fraction semispan) (a)	$C_{L_{max}}$	b_s (fraction semispan) (a)	$C_{L_{max}}$	b_s (fraction semispan) (a)	$C_{L_{max}}$	b_s (fraction semispan) (a)	$C_{L_{max}}$
Reynolds number 4,000,000										
6	0 to 0.03	1.21	0 to 0.31	1.39	0.35 to 0.65	1.38	0.45 to 0.66	1.34	0.66 to 0.81	1.31
12	0 to .03	1.22	0 to .17	1.38	.19 to .42	1.40	.28 to .68	1.39	.40 to .83	1.37
18	0 to .03	1.23	0 to .14	1.36	.11 to .34	1.40	.20 to .46	1.39	.32 to .85	1.39
Reynolds number 8,000,000										
6	0 to 0.03	1.23	0 to 0.25	1.41	0.25 to 0.53	1.42	0.39 to 0.58	1.38	0.43 to 0.70	1.37
12	0 to .03	1.25	0 to .16	1.40	.11 to .43	1.43	.25 to .45	1.41	.35 to .59	1.39
18	0 to .03	1.26	0 to .12	1.37	.06 to .27	1.41	.13 to .45	1.43	.22 to .57	1.41
Reynolds number 14,000,000										
6	0 to 0.03	1.22	0 to 0.17	1.38	0.26 to 0.46	1.41	0.31 to 0.52	1.38	0.37 to 0.63	1.38
12	0 to .03	1.24	0 to .14	1.38	.10 to .35	1.42	.25 to .39	1.39	.27 to .50	1.39
18	0 to .03	1.25	0 to .08	1.36	.02 to .25	1.39	.14 to .34	1.40	.20 to .48	1.40

[a]Region of initial stall, b_s.

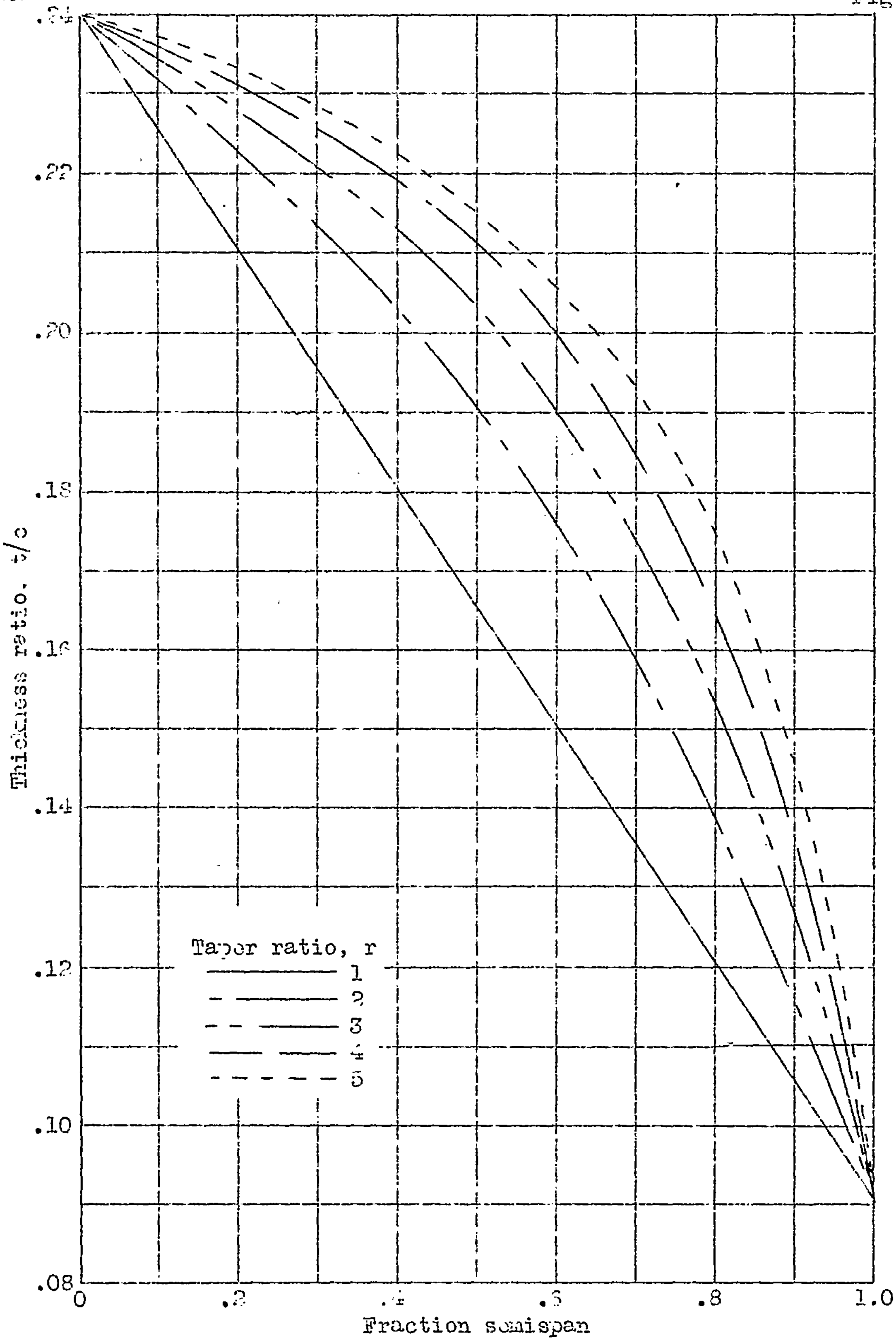
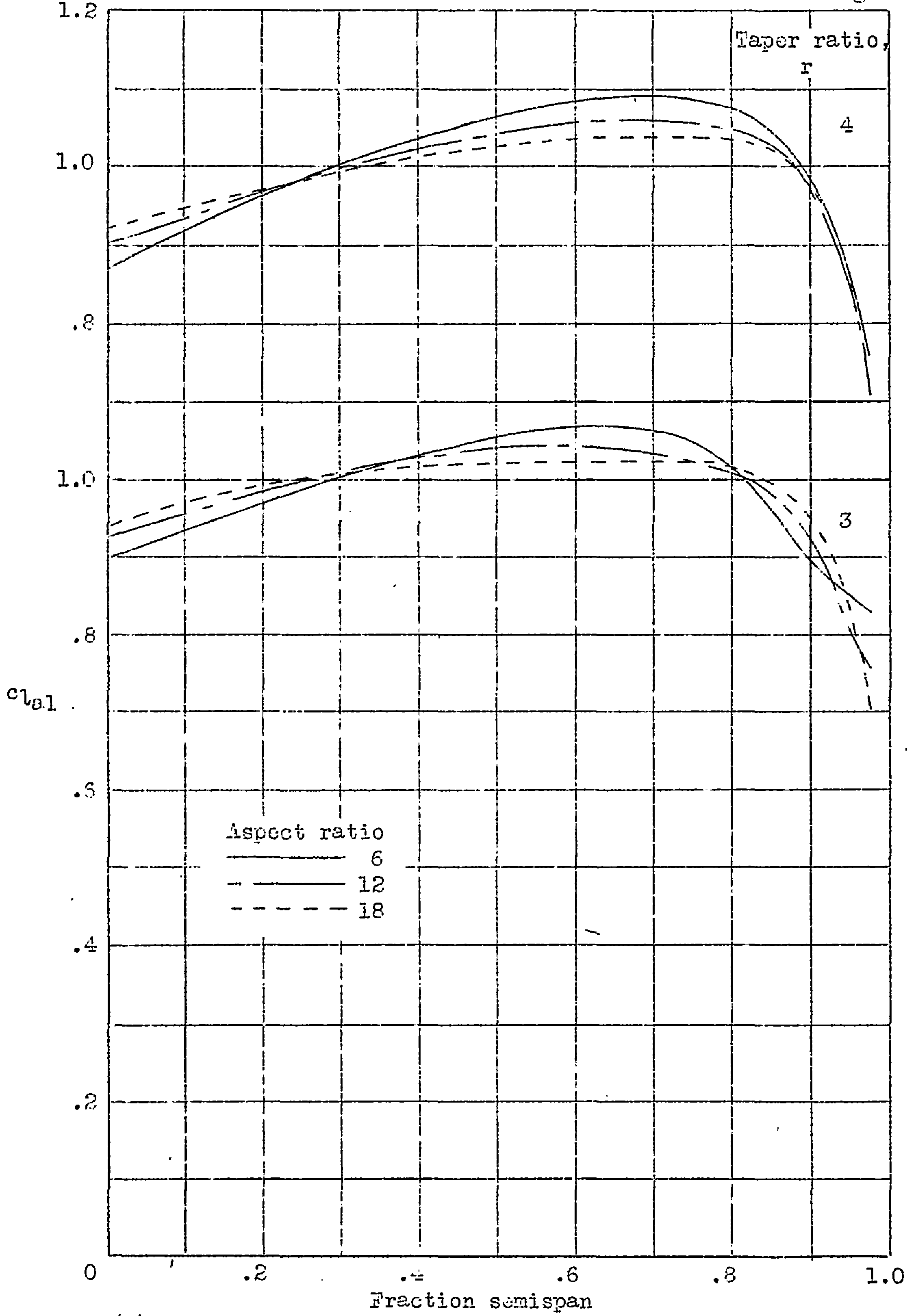


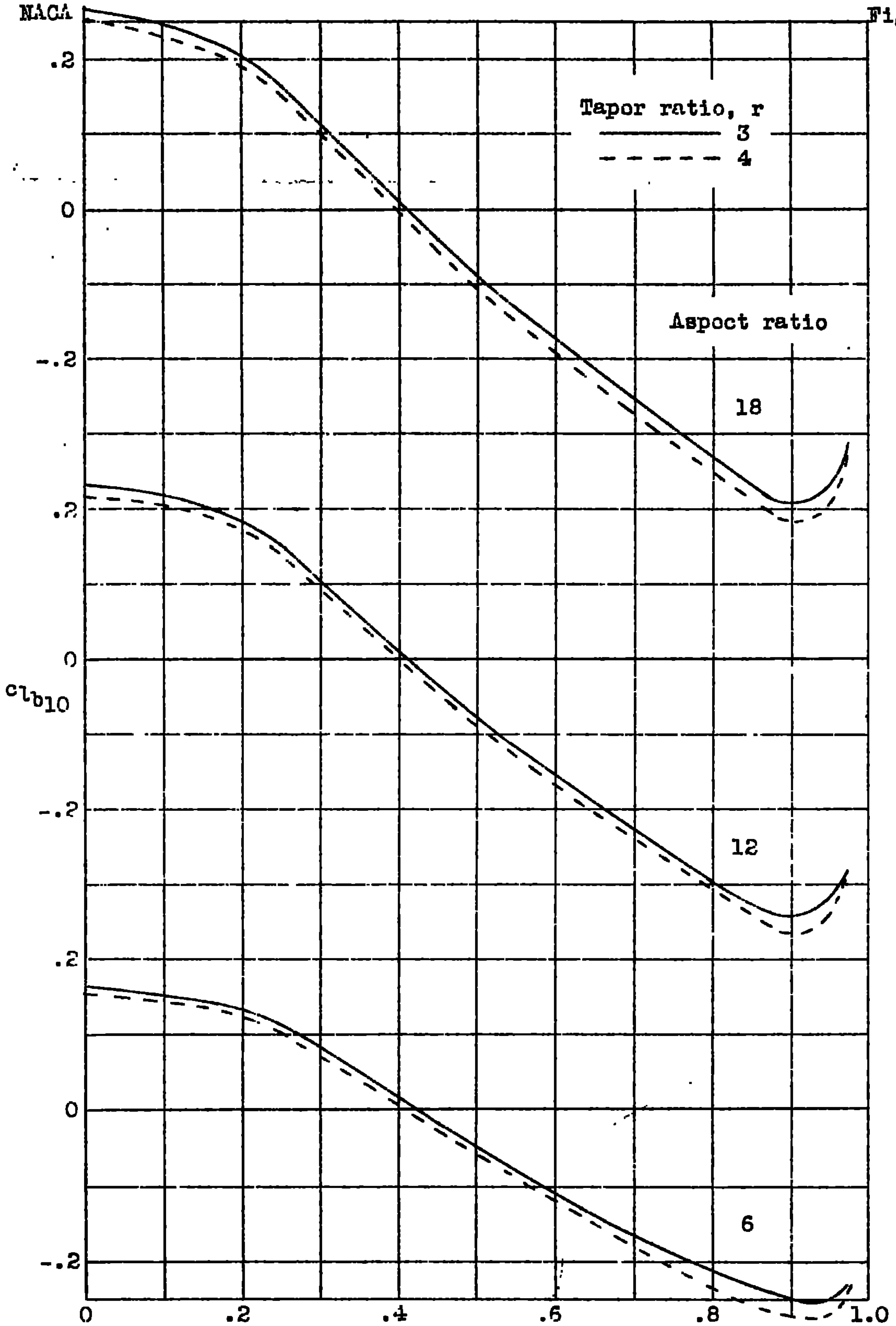
Figure 1.- Typical variation of thickness ratio with taper; NACA 23024-09 airfoil.

Figure 2a,b.- Distribution of lift over semispan.



(a) No twist; C_L, 1.0

Figure 2a,b.- Distribution of lift over semispan.



(b) Washout, 10°; C_L, 0; linear twist distribution.
Figure 2.-(Concluded).

NACA Fig. 3a

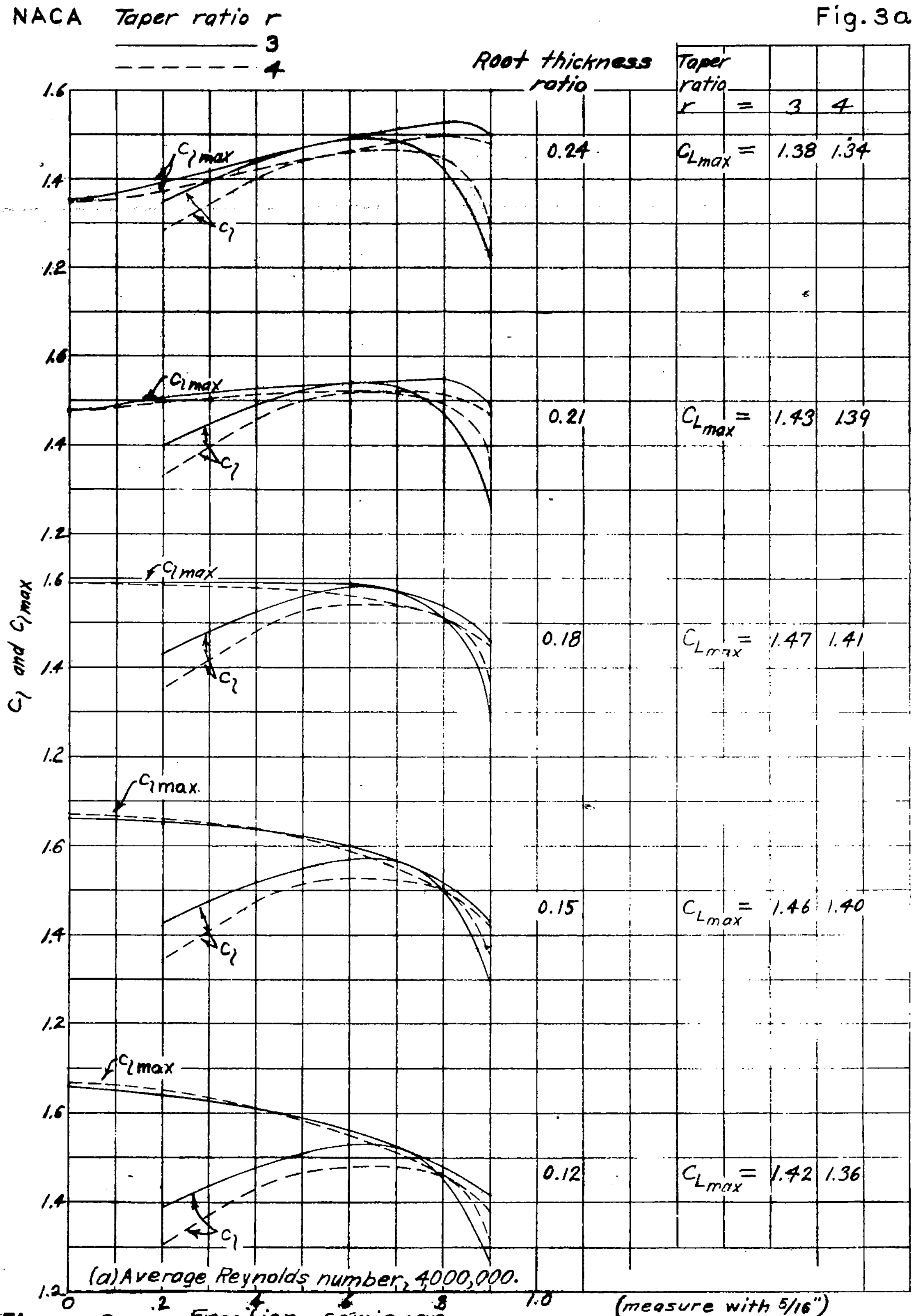


Figure 3 a to c. – Distribution of c_l and $c_{l\,max}$ over semispan. Tip thickness ratio, 0.09; NACA 230 series airfoils; aspect ratio, 6.

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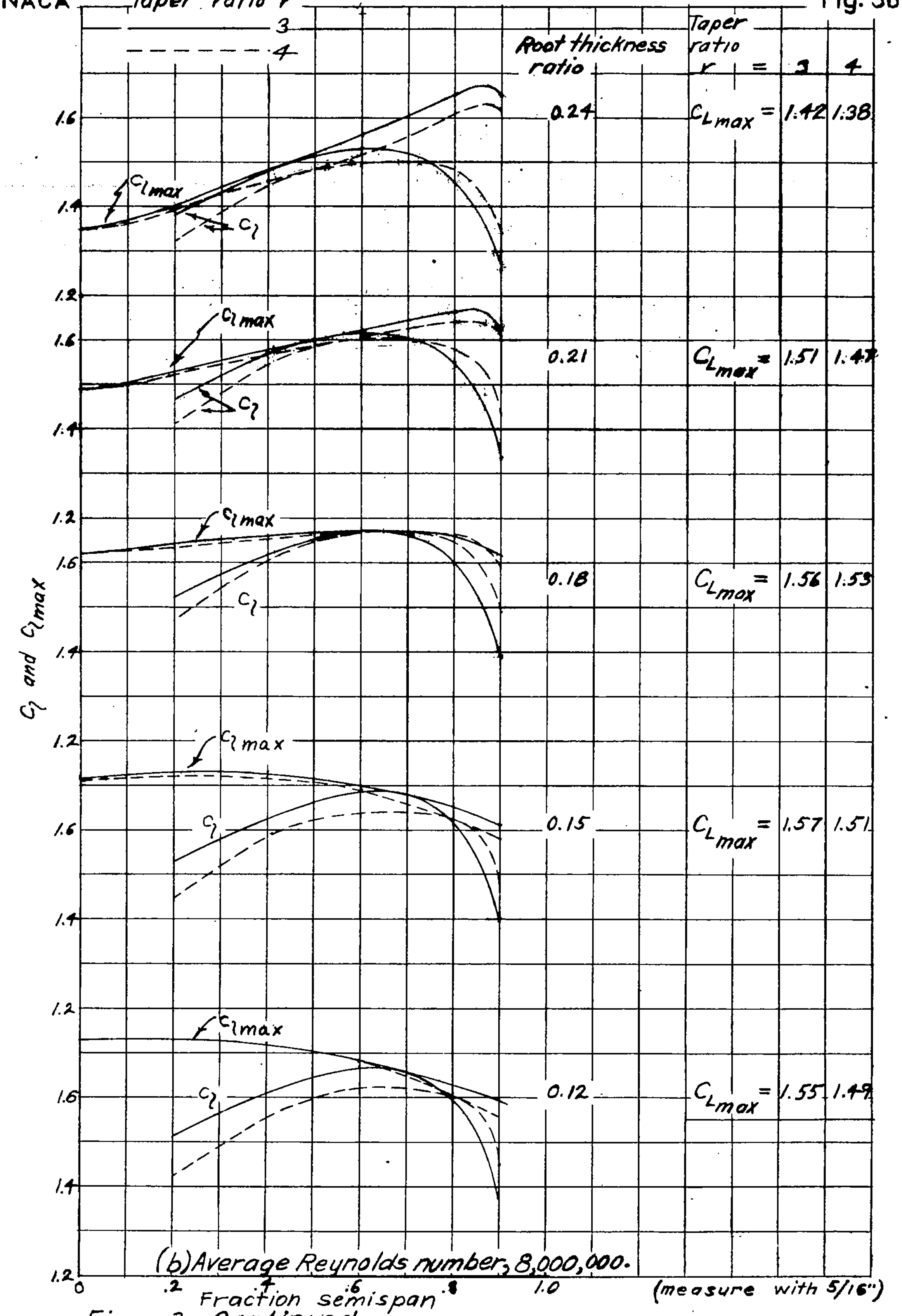
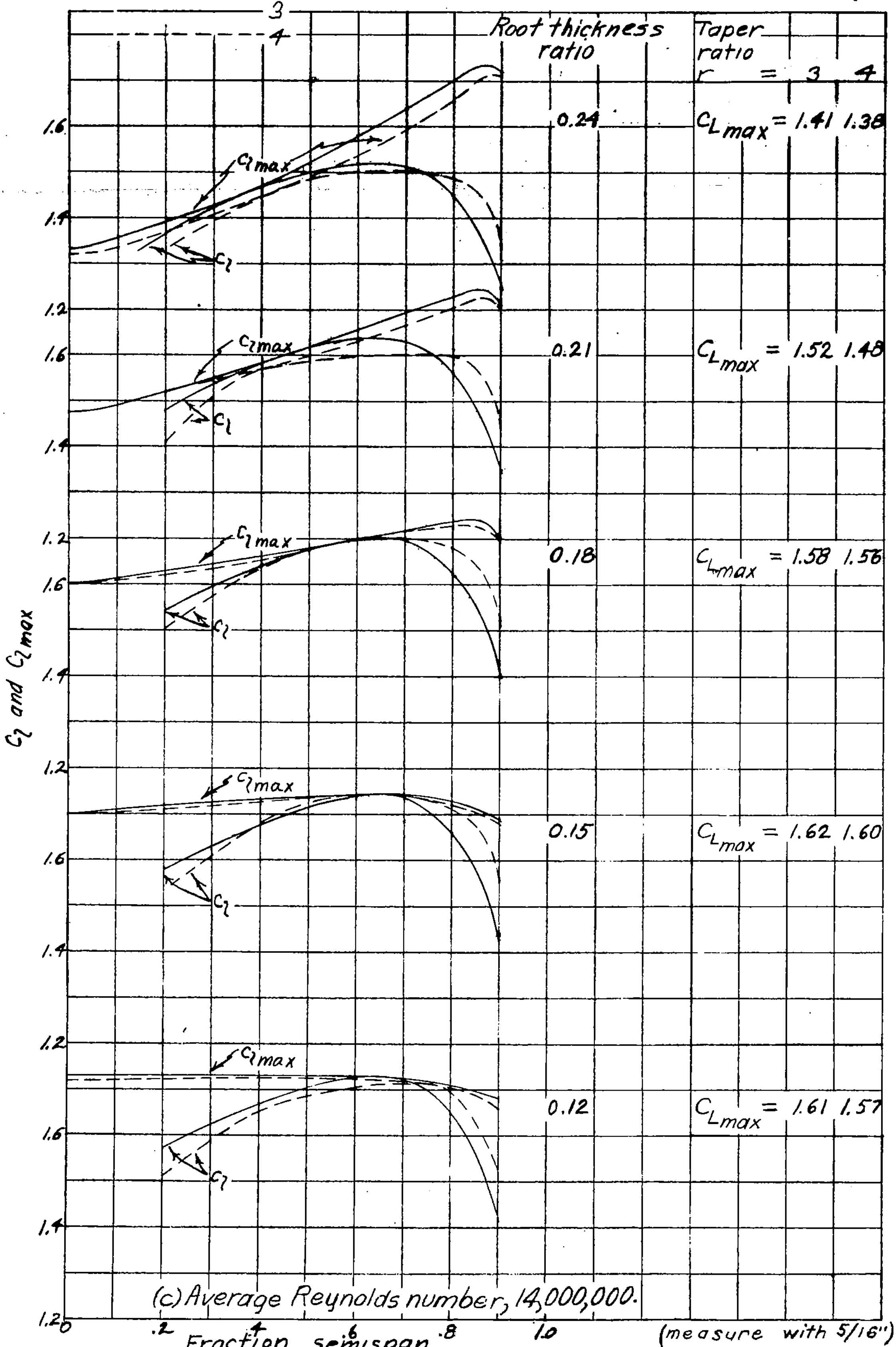


(b) Average Reynolds number, 8,000,000.

Figure 3.- Continued.



(c) Average Reynolds number, 14,000,000.

Figure 3.- Concluded.

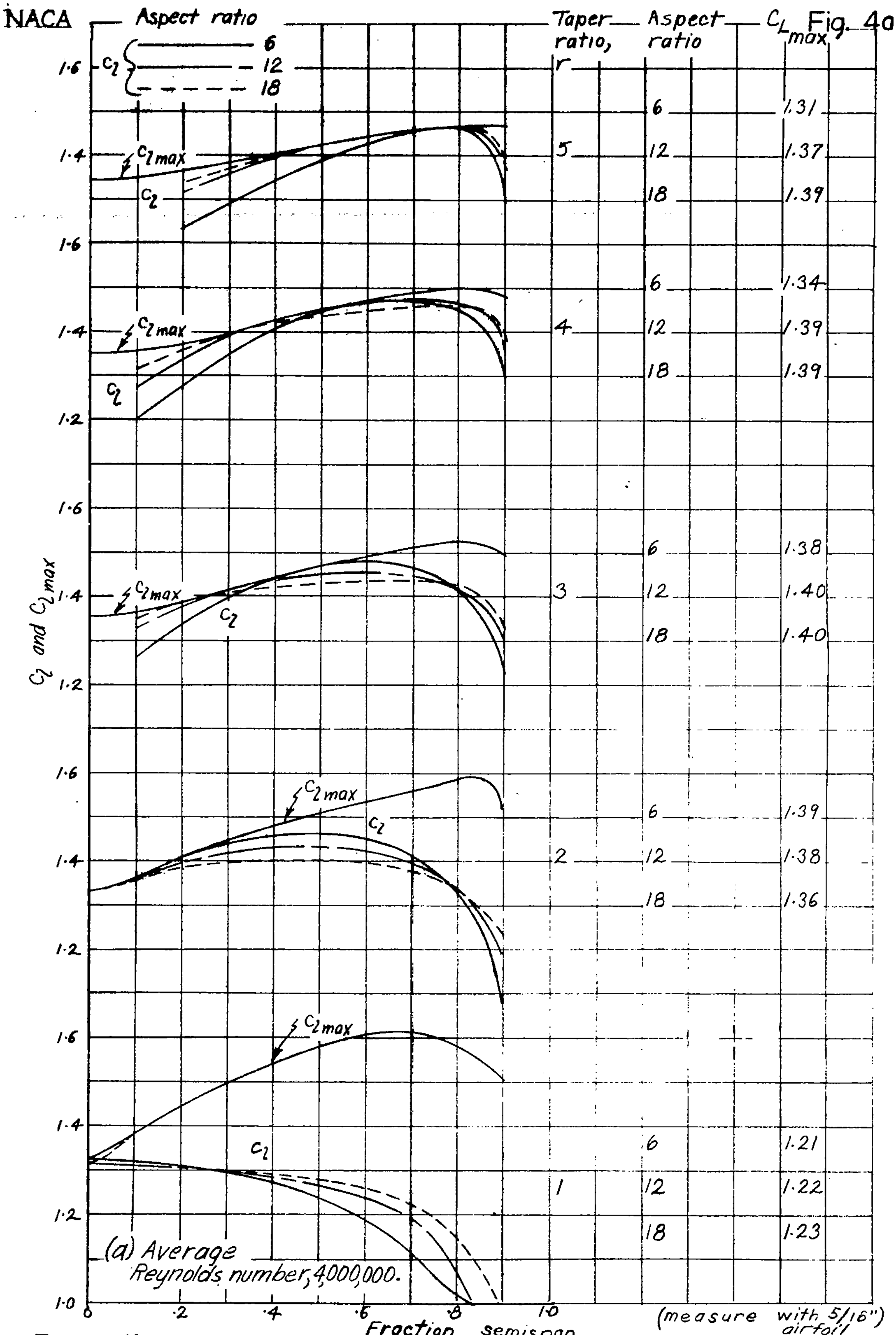


Figure 4(a to c)- Distribution of c_l and $c_{l_{max}}$ over semispan. NACA 23024-09

NACA Fig 4b

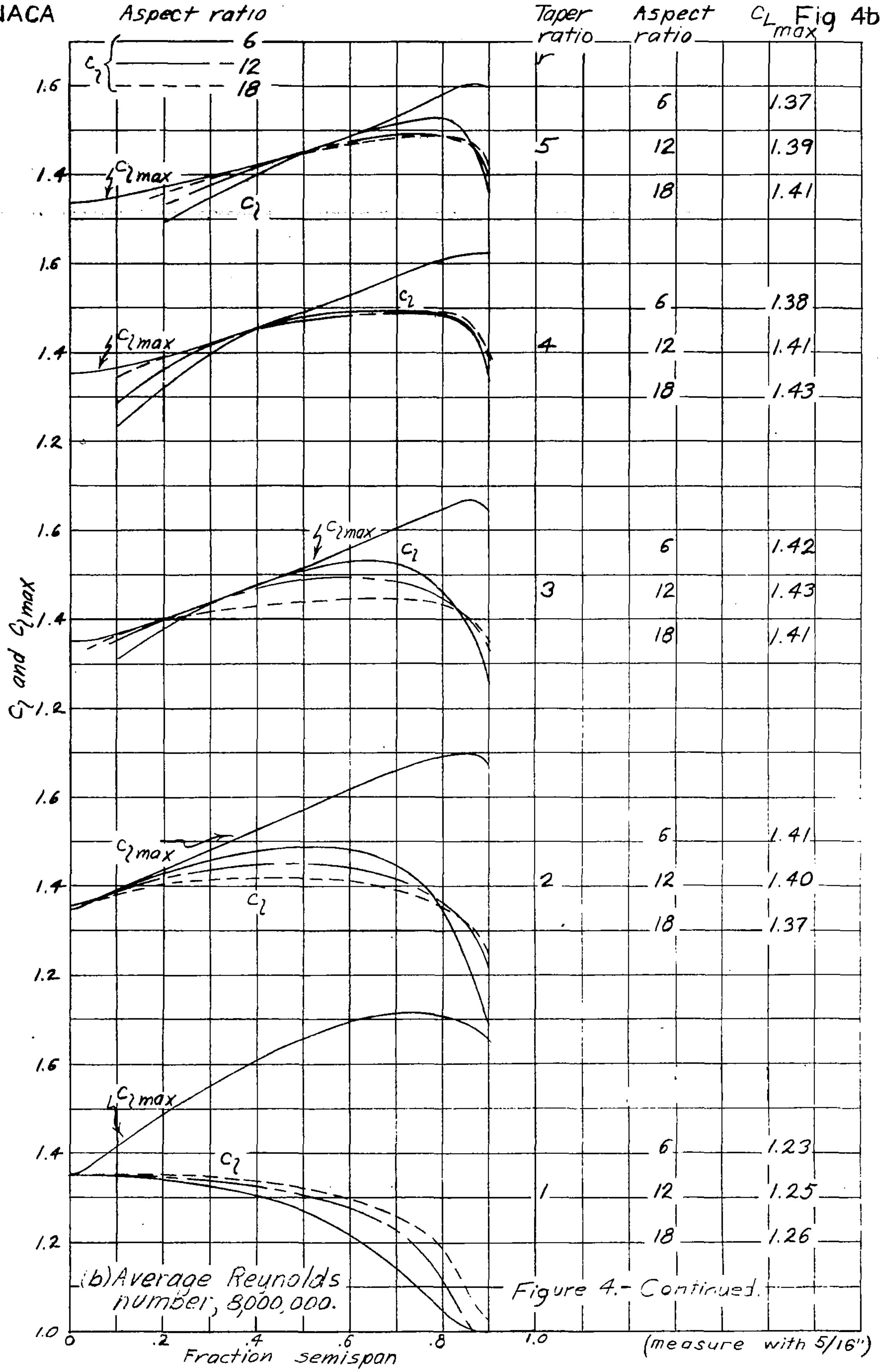


Figure 4.- Continued.

NACA Fig. 4c

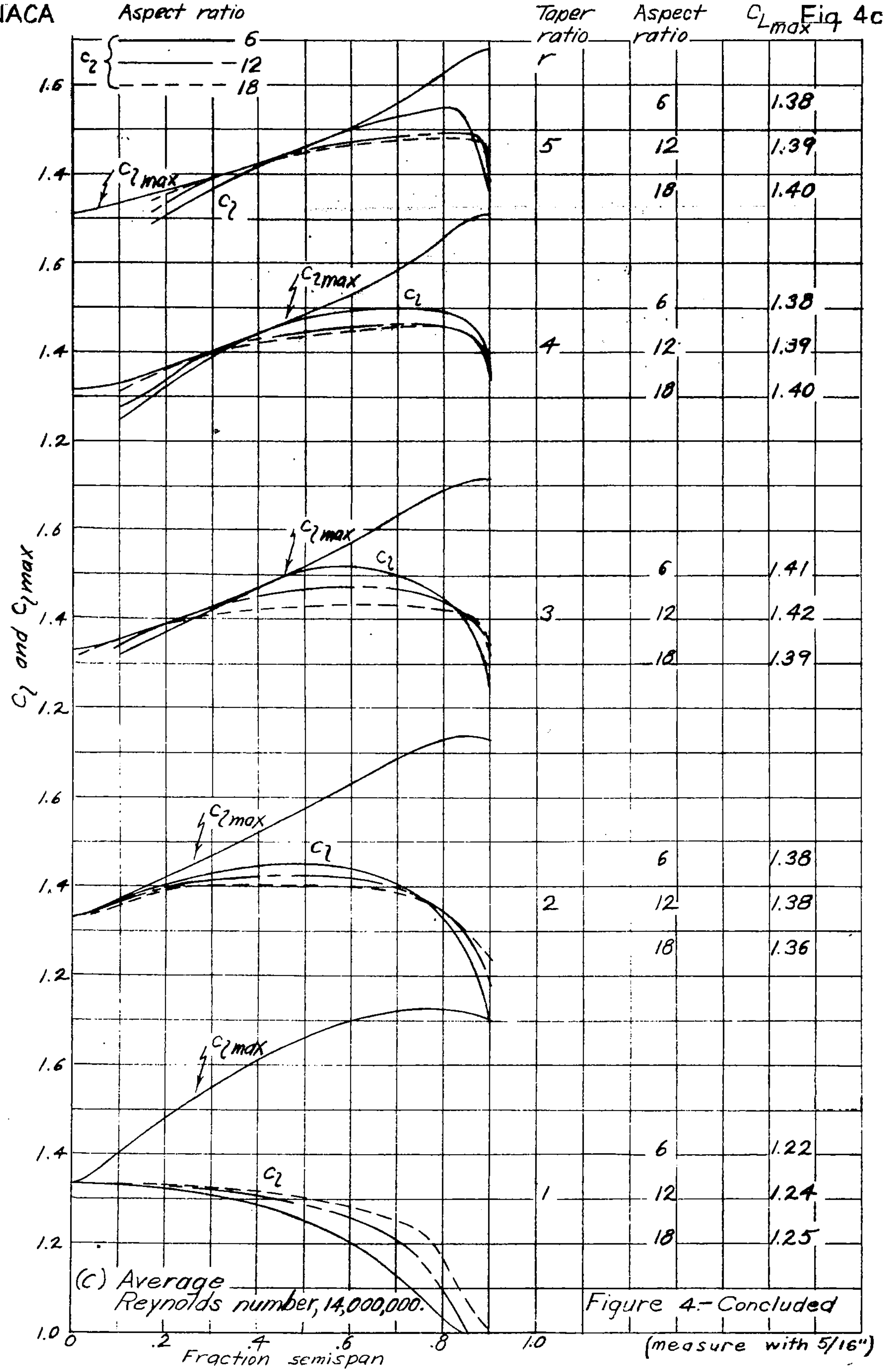


Figure 4.- Concluded